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RESEARCH ARTICLE

STATE OF ATMOSPHERIC POLLUTION IN WEST AFRICA: HEALTH IMPACT

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ABSTRACT

Currently, the issue of environmental pollution is becoming a growing concern in terms of both health risks and obstacles to development particularly in developing countries such as those in the West African region. This study contributes to the strengthening of existing databases on air pollution in West Africa. The study method consisted of selecting articles from the following databases: "Pub Med", "SPORT-Discus", "Scopus" and "Google Scholar". The keywords "air pollution", "West Africa", "health effects on earth", "demography in Africa", "socio-economic status", and "origin of pollution" were used to search for articles in these databases. The results observed at the end of this research made it possible to increase the state of knowledge relative to the demographic and socio-economic contexts of West Africa before describing the characteristics of the different atmospheric layers such as the troposphere, the tropopause and the stratosphere. The various atmospheric pollutants contained in these layers and their recognized effects on health were discussed. From this synthesis of scientific studies on air pollution in West Africa, we found that there are major health concerns such as early aging, progressive regression of the central and peripheral nervous system, depression of lung function and weakened immune defenses. Reducing the exposure of air pollution, improving air quality and setting up air quality monitoring and ambient air standards is essential in West Africa.

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INTRODUCTION

Air pollution is currently a danger to public health. A recent study has shown that in 2013, air pollution was responsible for 5.5 million deaths worldwide, and assessments anticipate between 6 and 9 million deaths by 2060 (OCDE 2016). In France, a country where diesel fuel is predominant (60% of vehicles in the car fleet), the number of premature deaths per year due to pollution ranges between 17,000 and 48,000 according to the Aphekom project (Improving Knowledge and Communication for Decision Making on Air Pollution and Health in Europe), and diesel fuel represents an economic cost of approximately 30 billion Euros (Scarwell 2017). Air pollution stems not only from industry emissions but also from heating and vehicle exhaust. We can classify air pollutants into the following two groups: pollutants and primary atmospheric particles and secondary pollutants. Primary pollutants are composed of heavy metals (lead, arsenic, cadmium, nickel, and mercury), sulfur dioxide (SO_2), volatile organic compounds (VOCs), carbon monoxide (CO) and aluminum oxide. The primary atmospheric particles are classified according to their size because of their more or less deep penetration into the pulmonary system as follows: PM_{10} (suspended particulate matter with a diameter less than or equal to 10 microns) and $PM_{2.5}$ (particulate matter in suspension less than or equal to 2.5 microns in diameter). Secondary atmospheric pollutants arise from the mechanisms of oxidation, nucleation, condensation, and coagulation, and they transform gaseous compounds in the

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atmosphere into liquid or solid particles. Ammonium nitrate, ammonia (NH_3) and ozone, which is a major source of hydroxyl radicals, contribute to the oxidizing power of the atmosphere (Charpin *et al.* 2016). According to the WHO (2015), pollution is the main cause of health inequalities as it affects women, children, and the elderly from low-income populations. In fact, because of a lack of income to cope with expenses for the sake of health, people from the low-income class continue to cook and heat with solid fuels such as wood, charcoal, coal or manure. As a result, the health risks associated with air pollution are highest in families with low socio-economic status and in developing countries (Pinault *et al.,* 2017) showed that exposure to ambient $PM_{2.5}$ was associated with an increased risk of non accidental mortality and cardiovascular and respiratory diseases in Canada. The $PM_{2.5}$ data from personal-level estimates were determined for Caucasian, aboriginal, visible minority (non-white), immigrant, and socio-economic groups (household income, highest level of education).

The results of this study show that $PM_{2.5}$ exposure was higher at 1.61μg/m^3 for the visible minority population (non-white-skin compared to white populations), and 1.55μg/m^3 in the case of immigrants (compared to non-immigrants).In the West African region, Mama *et al.* (2013), in a study aimed at the quantitative evaluation of primary and secondary pollutants, showed in Benin that the levels of these pollutants (SO_2, NO_2, CO and Pb) are alarming (214.7 mg/m^3 for CO, 0.3 mg/m^3 for NO_2). For lead, the amount varies depending on the exposure time. The highest values are 470μg for an area of 1600cm_2 and an exposure time of 12 hours. This rise in values is due to the proliferation and use of vehicles called “France goodbye or come from France” that lack technology that can limit pollutants and two-wheeled motorcycles using adulterated gasoline, commonly called “kpayo”. In this context, a recent study in the Ivory Coast showed that 64% of the vehicles used in the transport sector are 20 years older or more, showing an aging of the automobile fleet, which, in turn, is a source of pollution (Tra and Adou 2017). This result led other researchers to make a comparative study between motorcycle taxi drivers and a control group in order to see if this occupation is associated with respiratory disorders in the context of urban pollution. The latter were exposed to average levels of CO (7.6 ± 4.9ppm vs. 5.4 ± 3.8ppm).

The results of this study showed that motorcycle taxi drivers were more exposed to urban traffic pollution than the control group, although the difference was not significant (Lawin *et al.* 2016).The consequences of atmospheric pollution for economic and health levels are well established. In terms of the cost of time lost in a traffic jam, for Permanent State Agents in vehicles in Benin lost the State of Benin per day an average of 64 USD per month. Those riding on motorbikes lost on average 47 USD per month (Akiyo *et al.* 2016). In terms of health, the functional exploration tests carried out in 156 children in Cotonou revealed that children living near car traffic are at risk of developing respiratory disorders (Messan *et al.* 2011). Some authors have also reported that PAHs as well as fine particles ($PM_{2.5}$) measured in Dakar (Senegal) induce inflammatory reactions (Dieme *et al.* 2012). Therefore, there are expressions of bio-markers such as $CYP1A_1$ or $CYP1B_1$ (Cytochrome P450 $1A_1$ or $1B_1$), TNF-α (tumor necrosis factor), IL-1β, IL-6, and / or IL-8that have been induced by these particles (Dieme *et al.* 2012). The fine particles collected in the Ivory Coast at three different sites (urban, rural and industrial) caused oxidative damage when they came into contact with lung cells (A549) in a study conducted by Kouassi *et al.* (2009). These different studies carried out over the last ten years show that air pollution is an important topic in Africa and concerns not only the decision-makers but also the scientific community. These studies show that people of all age levels (children, young and old) and occupational categories are exposed to pollution in general. On the other hand, no study has shown the impact of a pollutant and the short-term and long-term effects on health. This question is the focus of this issue review which takes stock of the state of knowledge, the atmospheric environment, the synthesis of scientific studies and the possibility of new contributions.

MATERIALS AND METHODS

Scientific articles were selected from the “Pub Med”, “SPORT-Discus”, “Scopus” and “Google Scholar” databases. The keywords “pollution”, “West Africa”, “health effects”, “demography in Africa”, “socio-economic status”, and “origin of pollution” were used to search for the articles. The articles references were identified using the ISI-Research Soft Endnote Software. These data have been used to report on pollution in West Africa and the influence on the health of populations in the short, medium and long term. Studies in French and English relating to West Africa were selected as the inclusion criteria. The articles that related continents besides Africa were excluded from the study.

Status of current knowledge on the subject

Framework, demographic and socio-economic contexts: West Africa is part of sub-Saharan Africa and includes 15 countries (Benin, Burkina Faso, Cape Verde, Côte d'Ivoire, Gambia, Ghana, Guinea, Guinea-Bissau, Liberia, Mali, Niger, Burkina Faso, Nigeria, Senegal, Sierra Leone and Togo). West Africa has an area of approximately 6.14 million square km. The work of Tabutin and Schoumaker (2004) shows that by 2020, 50% of the African population will be urban, more than half of whom will be in West Africa. This growth of the urban African population poses a number of problems. With increasing poverty and a low standard of living, there is a lack of reception facilities and, as a result, enormous environmental and social and economic problems remain. The socio-economic situation of African countries south of the Sahara is not ideal despite the implementation of the “Millennium Development Goals (MDGs)”, which aim to reducing extreme poverty and hunger, improving health and education and ensuring a sustainable environment. We can see the persistence of real problems including the low school enrollment rates of the population and especially the environmental pollution generated by urban transport in West African capitals. Indeed, the urban population growth, the migration of young people from villages to cities, the wave of layoffs of public sector workers following the Structural Adjustment Program imposed by the Bretton Woods Institutions in the 1980s and the devaluation of the money of the African Financial Community in 1994 have induced a very high rate of unemployment in capital cities in West Africa. This crisis is felt strongly in the main West African capitals where the lack of a public transport policy, the weak urban transport network and the low socio-economic level of Africans have favored the emergence of an informal sector of activities animated by motorcycle drivers.

Of these drivers, 90% have used motorcycles and motorcars that are imported from northern countries. These devices, which are handled by hundreds of thousands of drivers, generate thick, black fumes in the atmosphere especially at intersections and at rush hour. These fumes emanate from the incomplete combustion of hydrocarbons and other particles due to mechanical engine failures that are the result of poor maintenance and poor quality of fuel fraudulently imported from neighboring oil-exporting countries. Pollution from the use of fuel oil as a source of energy is another important source of gaseous and particulate pollution. Thus, the very high levels of pollution observed in West Africa are closely linked to the demographic and socio-economic situation. These hundreds of thousands of devices registered in each West African capital are purveyors of toxic gases that contribute to the degradation of the atmospheric environment, which is not without effect on the health of the population.

Atmospheric environment: The gaseous envelope that surrounds the Earth is the atmosphere, which can be broken down into two parts. One part comprises a mixture of dry air and water vapor, and the other part comprises condensed water or fine crystals, pollutants and aerosols. In the vertical plane, the atmosphere is divided into several layers, and the most important, the troposphere and the stratosphere layers, are in the lower part of the atmosphere. The troposphere is approximately ten kilometers thick above the Earth's surface (Fishman *et al.,* 1990; Fishman and Brackett 1997).

Atmospheric pollution: Air pollution is due to human activities that result from stationary sources, such as fireplaces and industry, domestic and agricultural activities, and mobile sources, such as automobile traffic and air navigation. Among the primary pollutants directly emitted into ambient airare oxidized or reduced compounds of sulfur and nitrogen, carbon oxides, volatile organic compounds, particles and metals. Some of these substances undergo chemical transformations to give rise to secondary pollutants, such as ozone and sulphates. Ozone that is emitted from four regions globally influences the composition of the troposphere (Fry *et al.* 2012). In addition, the composition of biomass induces a significant increase of the ozone contained in troposphere (Olson *et al.,* 1996; Thompson et al. 1996).

Major air pollutants and their effects on the state of health: Polluted air contains hundreds of pollutants, including sulfur dioxide (SO_2), nitrogen oxides (NOx), volatile organic compounds (VOCs), particulates and dusts (PM_{10}, $PM_{2.5}$), carbon monoxide (CO), ozone (O_3) and the heavy metals lead (Pb), mercury (Hg) and cadmium (Cd).

Sulfur dioxide (SO_2): SO_2that is in contact with the moisture in the air is transformed into sulfuric acid, which contributes to the phenomenon of acid rain. SO_2 comes from the use of fuels containing fuel oil and coal. It works in synergy with other substances, especially with fine particles. Its effects are amplified by smoking. Like all pollutants, SO_2 irritates the mucous membranes and is associated with many respiratory diseases.

Nitrogen oxides (NOx): Approximately 95% of nitrogen oxides are the consequence of the use of fossil fuels. Road traffic makes up 59% and is the main source of fossil fuels. Nitrogen dioxide (NO_2) is an irritant gas to the bronchi and the respiratory airways. NO_2 participates in acid rain events, the formation of tropospheric ozone, of which it is one of the precursors, the formation of the stratospheric ozone layer and the greenhouse effect. Nitrogen oxides also contribute to the formation of photochemical pollutants, such as ozone, which are harmful to health and contribute to the phenomenon of acid rain.

Volatile organic compounds (VOCs): VOCs are gaseous organic compounds that are in the atmosphere, and hydrocarbons are the main type of VOCs. Road traffic, domestic or industrial use of paint and varnish are the three main sources of VOCs, and solvents evaporate during drying and evaporation. Along with nitrogen oxides and carbon monoxide, VOCs contribute to the formation of tropospheric ozone. The monocyclic aromatic hydrocarbons benzene, toluene and xylene are used in the composition of fuels and are found in the atmosphere either by exhaust gas or by the evaporation of fuels from tanks or service stations. The effects of VOCs on human health vary greatly, from olfactory discomfort to mutagenic and carcinogenic effects through various irritations and decreases in respiratory capacity. VOCs play a major role in the complex mechanisms of ozone that forms in the troposphere. They also affect the processes that lead to the greenhouse effect and the ozone hole. Some VOCs, such as formaldehyde and benzene, are carcinogenic.

Particles / dusts: The various combustions resulting from road traffic and industrial activities are the origin of particles or dust. Particles with a mean diameter of less than 10 µm are suspended in the air and undergo the phenomenon of sedimentation as a function of the temperature of ambient air. However, particles with diameters greater than 1µm are deposited more or less rapidly in the neighborhood of their emission sources. The particles penetrate deeply into the pulmonary tree of the lungs, according to their granulometry. The finest particles can, at concentrations that are relatively low, irritate the lower respiratory tract and impair respiratory function. Ambient air pollution and the measurement of fine particles in three Cameroonian cities, Bafoussam, Bamenda and Yaoundé, have shown the extent of the phenomenon similar to other countries in the region (Antoneland Chowdhury 2014)9]. Some particles even have mutagenic and carcinogenic properties, while others are involved in the genesis of respiratory and cardiovascular disorders.

Heavy metals: Heavy metals include high density metals, such as lead (Pb), mercury (Hg), cadmium (Cd), and nickel (Ni). Heavy metals exist in the form of particles with the exception of mercury, which is mainly gaseous. Heavy metals come from combustion and from some industrial processes that incinerate waste. They can accumulate in the body and cause short and / or long-term toxic effects depending on the type of metal. Disorders of the nervous system and renal and hepatic function have been recorded. Toxic metals contaminate soil and food. They accumulate in living organisms and disturb balance and biological mechanisms.

Carbon monoxide (CO): arbon monoxide comes from incomplete combustion. It is emitted largely by road traffic by a group or individuals and by poorly regulated heaters. In the atmosphere, carbon monoxide combines with oxygen to form carbon dioxide (CO_2). CO attaches to oxygen instead of blood hemoglobin and can lead to breathing problems, asphyxiating effects, headaches, and heart problems.

Ozone (O3): Ozone, a major secondary pollutant, is formed by the action of the sun's ultraviolet rays on primary pollutants such as nitrogen oxides, volatile organic compounds and carbon monoxide. Ozone is a chemical pollutant present at the soil level; we speak of tropospheric ozone that is distinguished from stratospheric ozone (ozone layer). Ozone is an aggressive gas that easily penetrates to the thinner airways. It causes coughing and pulmonary depression as well as eye irritation. Its effects are variable from one individual to another.

Origins of atmospheric pollution in West Africa: Much of the air pollution in West Africa is of organic origin. In energy, biomass is the living mass considered from the viewpoint of the energy that can be obtained by combustion or fermentation from animal excrement, fossil waste, etc. It includes all organic materials that can become sources of energy. Thus, there is burning and intensive use of biomass and, more particularly, wood in developing countries for several reasons. For millions of years, wood has been used as a source of energy for heating and cooking (Fry *et al.,* 2012; Rouvière, 2006). This situation persists in developing countries, especially those in West Africa, which for the most part have relatively low standards of living. In addition, Olson *et al.* (1996) and Anderson and Fishwik (1984) concluded that the use of firewood is related to its relatively low cost compared to the high cost of investments to acquire kerosene or gas in kitchens since electricity is not accessible to everyone. Similarly, Lang (2006) pointed out that this situation is also linked to the increase in the price of gas because of a change in the subsidy policy as well as the increase in the price on the world market. The combustion of biomass is responsible for the emission of a large amount of gases and particles that contribute to the modification of air quality. These gases and particles play an active role in pollution. Indeed, these particles reduce the solar radiation that should reach the soil and thus modify the variation of the diurnal temperature of the clouds. Monsoon winds are generally laden with sea salts, and Saharan winds generate dust from forest and domestic fires and aging fleets. Road traffic in capitals is very dense, and fleets have several hundred new vehicles but are mostly second-hand imported vehicles from Europe. The fuels used by these vehicles are not of good quality.

It is important to note that used vehicles consume more fuel and are not equipped with the latest technologies to control gas emissions. These vehicles, as well as hundreds of thousands of taxi motorcycles widely used in the West African space, emit exhaust with quantitative and qualitative composition that depends on the type of fuel, the type of engine, and the age of the vehicle and the control system for gas emissions. In fact, several African countries import high-sulfur fuel with an average continental limit of 2000 parts per million (ppm), which is 200 times the tolerated threshold in Europe (Naidoo, 2016). Thus, the fuel obtained at the pump or in the informal sector is of dubious quality and generates several harmful pollutants to the body.

Synthesis of scientific studies on the subject: Globally, nearly 300 million people suffer from asthma and cardio-respiratory diseases (Morakinyo *et al.* 2017). Studies mainly suggest outdoor ambient air pollution as a factor in the induction or worsening of asthma and cardio-respiratory diseases. Indeed, globally, and particularly in Africa, these public health problems are linked to the fact that a large number of individuals are exposed daily to the pollutants contained in ambient air. Among the most important pollutants in ambient air are PM, O_3, SO_2, NO_2, CO and Pb (Jiang *et al.* 2016). Mainly, PM consists of pollutants from road traffic, transport and other complete and incomplete combustion processes (Falcon-Rodriguez *et al.* 2016). Research shows an association between the high level of pollution and the high intake number of people in hospitals with emergency cases of asthma attacks. According to the work of Botturi *et al.* (2011), prolonged exposure to ozone causes inflammation of the airways, bronchial hyper-reactivity and depression of lung function, while SO2 leads to broncho-constriction, and NO2causes bronchial inflammation as a precursor to the effects of ozone (Botturi et al.2011). On the other hand, PM exposure is believed to be at the root of oxidative stress. In South Africa, the work of Nkosi *et al.* (2016) found cardiovascular and respiratory diseases in elderly people living near mine dumps. In addition, Morakinyo *et al.* (2017) evaluated how health risks are associated with exposure to PM_{10}, NO_2, O_3 and CO pollutants. The results of these studies show that the pollutant concentrations observed are significantly higher than the tolerated norms. Chronic short-term exposure to the pollutants PM_{10}, NO_2, O_3 and CO as well as pollutants generated in the Sahara can lead to health risks (De Longueville *et al.* 2013).

In West Africa, Baumbach *et al.* (1995) evaluated the high levels of particulate and gaseous pollutants (PM, CO, NOx VOCs) at a traffic site in Lagos, Nigeria, in real time. In a study by Ozer *et al.* (2006), conducted at Nouakchott Airport in Mauritania, significant levels of TSP and PM_{10} were estimated from the relationship between horizontal visibility and PM concentration. In addition, Bohand *et al.* (2007) studied the consequences of the highly toxic waste dumped in the maritime waters of Abidjan by the ship Probo Koala chartered by Trafigura in 2006. The consequences of the waste dumping were related to breathing difficulties, nasal and intestinal bleeding and respiratory-distress. In Accra (Ghana) Arku *et al.* (2008) determined the spatial and temporal variations in $PM_{2.5}$ and PM_{10} levels at 2 sites following filter sampling every 24 hours for 3 weeks. Similarly, according to the work of Eliasson *et al.* (2009), spatio-temporal variations in $PM_{2.5}$ and PM_{10} concentrations were measured in a mobile manner in the cities of Ouagadougou (Burkina Faso), Dar es Salaam (Tanzania) and Gaborone (Botswana). According to the research of Weinstein *et al.* (2010), the same measurements of $PM_{2.5}$and PM_{10}were made in Conakry (Guinea) at three sites during the harmattan following filter sampling every 24 hours for one month. To understand the spatial variability of PM and the influence of source proximity on the concentration levels, Dionisio *et al.* (2010) conducted mobile and one-off measurements in Accra (Ghana), at four sites for one week. Chemical speciation initiated in Mbour (Senegal) by Flament *et al.* (2011) determined the chemical composition of aerosols after filter sampling every 24 hours for two weeks. In Ouagadougou (Burkina Faso), Lindén *et al.* (2012) highlighted the spatio-temporal variation in concentrations of PM_1, PM_{10} and some gaseous pollutants (CO, NOx, O_3, benzene and toluene) following point and mobile measurements in different locations. As one might expect, West Africa is confronted with the real problems of pollution of different natures as well as with its multiple impacts on the climate and on the health of the populations, since the World Health Organization (WHO) revealed that more than 300 million children around the world breathe toxic air (UNI and Katra 2017).

Thus, the Cooperation for University and Scientific Research (CUSR) has initiated a program called POLAC (Pollution in the African Capitals), which aims to study urban air pollution, both gaseous and particulate in the African Capitals to make the link with the health of the populations in two cities, Bamako and Dakar. The study carried out in Cotonou (Benin) by Ayiet al. (2006) in non-smoking taxi drivers revealed pro-inflammatory responses induced by the defense mechanisms of the human body. The work of Fall *et al.* (2008) that was carried out in Dakar to measure the health impact of exhaust gases on rat lung tissues revealed an alteration of glutathione metabolism in the presence of gasoline emissions. The study of Kouassi *et al.* (2009) in Abidjan (Ivory Coast) on the toxicity of PM collected at three sites (urban, rural and industrial) indicates the provocation of oxidative damage by these three types of aerosols when they are in contact with lung cells. By functional exploration tests carried out on 156 children living near dense car traffic in Cotonou (Benin), Messan *et al.* (2011) showed a high risk of airway disruption (Maina *et al.* 2018). In Dakar, studies conducted by Dieme *et al.* (2012) on the toxicological effects of particles collected from urban and rural sites have shown a greater pro-inflammatory response of particles collected in urban areas compared to the response of particles collected in rural areas. In Porto-Novo, Benin, the work of Messan *et al.* (2013) showed pulmonary function depression in motorcycle taxi drivers exposed to environmental pollutants in the exercise of their professional activities.

New contributions to the scientific field: Air pollution remains a major public health concern worldwide with significant population growth. For example, in the United States, the number of subjects over 60 will double in 2050, and the life expectancy will be 84.3 for men and 80 for women. In the world and in Africa, this trend has also been confirmed over the years and can be explained by the control of the characteristics of aging and the benefits of the preventive effects of regular sports practice. Indeed, the aging process is a progressive regression of motor activity of the central and peripheral nervous system, hormonal regulation, immune defenses and protein synthesis. Under these conditions, sports and controlled exercises would be the very basis of preventive medicine. This need is observed among athletes and relatively sedentary exercise in a polluted environment, a gradual increase in exercise intensity, an increase in ventilation frequency and hyperventilation of air laden with pollutants and automotive environmental. In fact, athletes develop high pulmonary flow rates compared to sedentary athletes and can even ventilate up to 100 $L.min^{-1}$ in steady state with maximum oxygen consumption greater than $67mL.kg^{1}.min^{-1}$. This large amount of ventilated air under unfavorable environmental and climatic conditions can cause damage to the respiratory airways of athletes. Because air circulation is important in exercise, the respiratory airways of these athletes are exposed frequently too many allergens. Additionally, the micro-lesions generated by hyperventilation are at the origin of cell permeability to Na^{+}, Cl^{-}, K^{+} and $Ca2^{+}$ ions. They induce the release of chemical mediators involved in the process. Hyperventilation in a polluted atmosphere would be detrimental to the health of the athlete and the sedentary person when they practice in an urban or peri-urban context. Most influential epidemiological studies have identified cancer risks associated with engine exhaust (Crump *et al.* 2016; Silverman *et al.* 2014). These exhaust gases, fine particles and organic solvent extracts are believed to be at the root of various forms of DNA damage and even mutations in bacteria Pearce *et al.* (2015). From this point of view, it is therefore conceivable that interactions of environmental factors with the determinants of health are exerted. These combinations of several pollutants represent a complex cocktail of components that are likely to generate so-called "emerging" diseases in sedentary individuals, children, adults and high-level athletes. These diseases could occur in the long term and cause many casualties in West Africa if practical arrangements are not made in a timely manner. This is why it is important for West African countries to integrate regional and international structures aimed at improving air quality, putting in place strict emission standards to guarantee progress in diesel technology and gasoline in the region. This would reduce the emissions of fine particles, nitrous oxide and hydrocarbons. In addition, the importation and production of quality fuel in Africa must be followed by internationally recognized independent quality-standards structures.

Conclusion

Atmospheric pollutants do not stop at the borders of the different countries of West Africa, and humans are directly or indirectly responsible for air pollution. It is important for several countries to come together to define strategies for combating environmental pollution by encouraging people to change their behavior. These measures should include reducing the exposure of people to air pollution particularly with regard to particulate matter, improving air quality and setting up devices that monitor the quality and standards of ambient air.

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